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LOW FLOW ESTIMATION IN ARTIFICIALLY INFLUENCED CATCHMENTS

TRAINING COURSE

Report 2

Estimation of Artificial Influences

Preface

A pre-requisite when adjusting natural flow estimates at a site for the impact of artificial influences is the ability to identify upstream influences and quantify their cumulative impact at the site. This Manual describes procedures for accumulating the licensed abstraction quantities, consented discharge quantities and reservoir release flows above a site of interest in order to make adjustments to the natural low flow statistics at ungauged locations. Procedures for defining the natural low flows statistics are given in Report No.1. Reference should be made to Report No. 3 for techniques to adjust the natural low flow statistics to take into account the impact of artificial influences. Report No. 4 describes the Micro LOW FLOWS V2.1 Software which has been developed to automatically calculate and adjust natural low flows in ungauged catchments.

Contents

1. Introduction

The estimation of low flow statistics is a major component in the determination of minimum acceptable flows, the issue of abstraction licences and discharge consents and the setting of compensation releases from reservoirs. Four methods of low flow estimation are commonly applied by the UK water industry.

1. Calculation of low flow statistics from continuous gauged flow data series.

2. Direct measurement of low flows at "ungauged" sites by an occasional programme of "spot" current meter measurements.

3. Estimation of time series of river flows using catchment-specific hydrological models.

4. Estimation of low flow statistics by multivariate models which relate low flows to catchment characteristics.

Where continuous flow data are available at the design site of interest method 1 is the most accurate and preferred technique. However, design information is generally required at ungauged locations and method 2, or more commonly, flow estimation procedures (methods 3 or 4) must be used.

The project Low Flow Estimation in Artificially Influenced Catchments (NRA R&D 274, Bullock et al., 1994) addressed the problem of assessing artificial influences on low flows and developed practical design techniques for low flow estimation in artificially-influenced catchments within the Micro LOW FLOWS software.

1.1 THE IMPACT OF ARTIFICIAL INFLUENCES ON LOW FLOWS

In natural rivers, the magnitude of low river flows are determined by climatic and runoff generation processes, amongst which effective rainfall, groundwater recharge and aquifer properties exert a dominant function (Gustard et al., 1992). However, as a result of the development of rivers and catchments for water resource purposes, few rivers now possess natural river flow regimes.

The early development of river regulation began in the late 18th Century, initially for navigation requirements and later to meet the growing demands of population centres. In upland areas small rivers were impounded to create reservoirs to store winter high flows to supplement summer low flows. The rate of large dam-building accelerated after 1950. The demands of the electricity industry, requiring water for cooling, and agriculture for irrigation have continued to grow. Since 1965 the emphasis in water management has been on direct river management, with reservoirs, abstractions, water treatment and inter-basin transfers providing for the integrated management of water resources.

As a consequence of this level of water development, many rivers in England and Wales exhibit artificially influenced river flow regimes and few rivers display natural flow characteristics.

The impact of man's development of water is most severe during periods of low flows when absolute volumes of water transfers represent a significantly higher proportion of the natural flow regime. As a broad indication of the extent of artificial influences upon low flows, fewer than 20% of the gauged low flow regimes, represent 'natural' conditions.

In addition, many artificial influences may operate seasonally, for example abstractions for spray irrigation. As a consequence it is necessary to consider estimation of low flow statistics on a monthly basis.

The impact of man's development of water is most severe during periods of low flows when absolute volumes of water transfers represent a significantly higher proportion of the natural flow regime. The extent of artificial influences upon low flows, fewer than 20% of the gauged low flow regimes, principally small rivers in England and Wales, represent 'natural' conditions

1.2 SUMMARY OF OVERALL METHOD

The overall methodology for estimating low flow statistics at ungauged sites in artificially influenced catchments, taking into account the effects of abstractions from surface and groundwater sources, discharges to surface water and compensation flows from impounding reservoirs can be summarised as follows:

1. Estimation of key natural low flow statistics at the ungauged site; specifically mean flow, monthly mean flow, monthly flow duration curves and mean monthly minima.

2. Identification of all artificial influences upstream of the ungauged site.

3. Quantification for all individual artificial influences upstream of actual values of monthly abstraction rates, discharge returns and reservoir compensation flows.

4. Simulation using the Theis analytical solution of the reduction in streamflow associated with abstractions from groundwater sources according to source and aquifer properties.

5. Construction of a monthly artificial influence profile at the ungauged site which represents the net impact of all upstream artificial influences.

6. Combination of the estimated natural monthly low flow statistics with the monthly artificial influence profile to estimate artificially influenced monthly low flow statistics.

7. Aggregation of monthly artificially influenced low flow statistics to produce annual artificially influenced low flow statistics for design purposes, notably mean flow, flow duration curves and low flow frequency statistics.

8. Estimation of natural and artificially influenced low flow statistics at numerous locations along a river to construct residual flow diagrams.

The overall methodology has been incorporated within Micro LOW FLOWS (Version 2.1) for automated application, although the methods could also be applied manually. The estimation procedures make use of natural low flow statistics and artificial influence data estimated on a monthly basis. This allows the seasonal variations in flows and operation of individual artificial influences to be taken into account.

1.3 LOW FLOW ESTIMATION MANUALS

Report No 1 introduced the procedures used for the estimation of natural monthly statistics at ungauged sites. This manual describes methods for the construction of monthly artificial influence profiles above the site of interest. This requires quantification of influences including abstraction licences, discharge consents and impounding reservoirs. The manual also considers the implementation of monthly artificial influence profiles within Micro LOW FLOWS. Reference should be made to Report No. 3 which discusses the adjustment of natural statistics and Report 4 which describes the Micro LOW FLOWS V2.1 Software in more detail.

Within this Manual, Section 2 describes the type of artificial influences which need to be considered. The procedure for quantifting the monthly abstraction, discharge rates and reservoir releases is discussed in Section 3 and includes methods for predicting monthly volumes in the absence of actual data. Section 4 describes methods for constructing the monthly influence profiles. The Micro LOW FLOWS V2.1 implementation of these procedures are described in Section 5.

In order to help explain the estimation procedure, worked examples are provided in Appendix A using data for the Pang catchment. Data for the Roman is provided to enable the reader to work through the methods during the syndicate exercises.

2. Types of Artificial Influence

Fewer than 20% of all gauged flow records represent "natural" conditions. As a result, it is essential to consider the impact of human development on low flows, especially when influence volumes represent a high proportion of the natural flow regime. The principal artificial influences considered are:

(i) abstractions from surface water;

(ii) abstractions from groundwater sources;

(iii) discharges to surface water;

(iv) impounding reservoirs.

These influences are briefly discussed within the following sections, but are presented in greater detail within NRA R&D Note 274, "Low Flow Estimation in Artificially Influenced catchments".

In order to be able to adjust low flow statistics it is essential to quantify the major influences upstream of the site of interest. Most artificial influences exhibit some degree of seasonality. As a result, it has been found to be necessary to consider the impact of artificial influences on a monthly basis. The cumulative impact of the artificial influences at a site can be represented by a monthly artificial influence profile. One of the key steps in the estimation of artificially influenced low flow statistics at the ungauged location is the construction of a monthly artificial influence profile based on data of water use upstream of the location. This requires:

(i) identification of all major occurrences of artificial influences upstream of the ungauged site;

(ii) quantification of monthly abstraction, discharge and reservoir impacts for each artificial influence;

(iii) summation of individual impacts to create a nett monthly artificial influence profile at the ungauged location.

A simple influence profile is illustrated in Figure 2.1. The variables held for particular influences are fully detailed in Appendix B of this report. The principal features for each influence type are presented below.

2.1 ABSTRACTION LICENCES

Abstraction licences can, in the simplest of cases, be straight forward in their authorisation of locations and volumes. However, in other cases, a licence can contain complex authorisations regarding multiple abstraction locations, different purposes, different seasonal periods and imposed licence conditions.

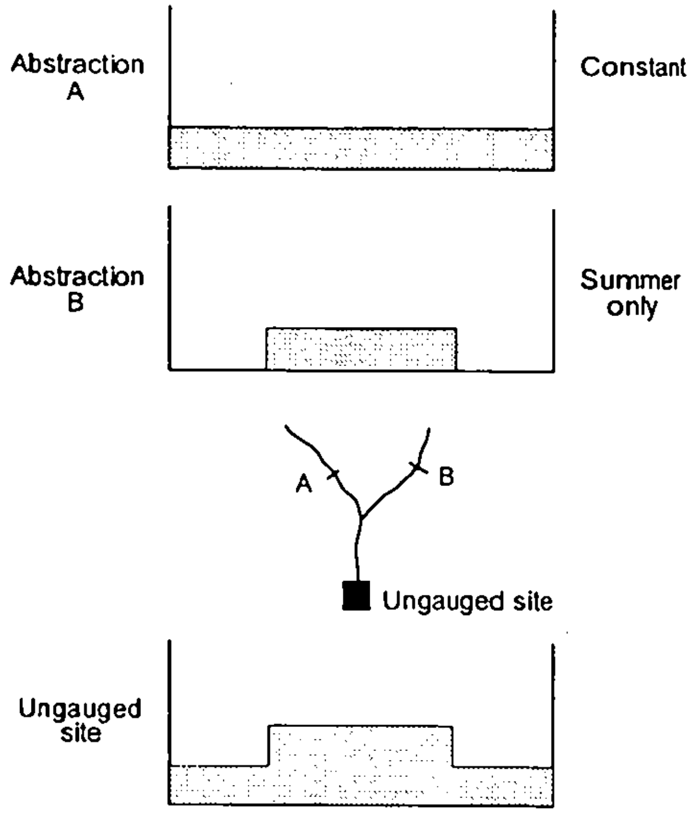


Figure 2.1 Construction of a monthly artificial influence profile

The National Rivers Authority holds information on complex licences which authorise the licence holders to abstract water under given constraints. The most complex single licence could potentially authorise abstractions under the following conditions:

(a) Water may be abstracted from two or more sites, at least one of which is a direct river abstraction and another is a groundwater abstraction. The direct river abstraction could be a reach of river covering up to several kilometres (but is more commonly a single point).

(b) While the overall (covering all sites) licence has maximum authorised abstraction rates (annual, daily and hourly) each individual site may have separate maximum abstraction rates (the sum of which cannot exceed the overall maximum rates). In the case of licences of right, maximum rates may not be imposed or maximum rates may be imposed without any associated protective conditions.

(c) An overall licence could authorise abstraction for different purposes, which might include a different purpose at each of the sites, but could include different purposes at any one individual site.

(d) In a complex situation with more than one purpose at an individual site, authorisation may be given to abstract for one purpose during one period of the year (for example spray irrigation during the summer) and for a second purpose during a different period of the year (for example general agriculture throughout the year). In certain cases, authorisation may be given to abstract for one purpose during two distinctly different periods of the year (for example, the spray irrigation purpose may authorise abstraction for irrigation for crop production during May to September and irrigation for frost protection during November to March). There are no rigid definitions of seasonal periods, and any combinations of start and end month can be used. This situation clearly becomes complex when dealing with a licence with multiple sites, purposes and licence periods.

(e) Licences may impose conditions on the abstractor to cease abstraction when certain conditions prevail, for example the flow at a prescribed flow point (or groundwater level at a monitoring borehole) falls below a particular threshold.

(f) Licences have different start dates, and may be currently operating or else have been revoked. Licence authorisations including location, purposes and quantity may have been revised on several occasions since the issue of the licence.

(g) On certain licences there is a commitment on the licence holder to either measure or to estimate the rates of actual abstraction (on a daily, monthly or annual basis) and to transfer actual rates to the NRA. However, actual rates are generally only available as a site total without a breakdown.

(h) Different purposes of abstraction can return contrasting volumes of water to the river (or aquifer to a lesser degree) in the vicinity of the abstraction after use of the water. This return of water may or may not require a discharge consent.

Due to these complexities it is most convenient to divide licence details into two types: overall licence details and site details (one or more set of which pertain to the overall licence). The key information that is required for establishing the influence profile for abstraction data include the following:

(1) The source of the abstraction (surface or groundwater abstractions);

(2) If the abstraction is from groundwater sources, the aquifer unit needs to be specified;

(3) The grid reference of each abstraction site;

(4) The purpose(s) of the abstraction, which determines the way in which monthly abstraction rates are predicted

(5) The authorised period of abstraction within the year;

(6) The licensed annual quantity which can be abstracted at each site and for each purpose;

(7) If available monthly actual abstraction rates need to be provided;

(8) For certain purposes such as cooling water, some of the abstracted water is returned. If this amount is not covered by a seperate discharge consent, then a percentage return factor needs to be included.

Refer to Appendix B for details of the file formats for loading data into the software.

2.2 DISCHARGE CONSENTS

As for abstraction licences, discharge consents can, in the simplest of cases, be straightforward in their authorisation of locations and rates, but in other cases can contain complex authorisation at multiple sites and for different purposes. Again, it is convenient to divide consent details into two types: overall consent conditions and site conditions.

The key information which is required for defining the monthly discharge consent include the following:

1. The grid reference of each discharge site;

2. The consented average discharge rate for the site;

3. The consented maximum discharge rate for the site;

4. The design dry weather flow;

5. Actual monthly discharges for the site, if available.

2.3 IMPOUNDING RESERVOIRS

Details of compensation flows and grid reference for principal impounding reservoirs have been collated within a national reservoir archive (Gustard *et al.*, 1987).The information which is held on the archive includes the following:

1. The grid reference of the dam site;

2. The primary function of the reservoir, for example, for hydropower, maintaining compensation flows, water supply and pumped storage;

3. The natural and total area draining into the reservoir;

4. The net and gross capacity of the reservoir;

5. The natural and estimate mean flow at the reservoir outflow or maintained flow point;

6. The compensation release policy and the compensation flow;

7. The natural yield of the reservoir

To incorporate the impact of the reservoir into the adjustment procedures, an estimate of typical monthly release flow in each month is required. Estimates of the compensation flow component of the monthly releases can be derived from the "compflow" variable on the archive and reference to the type of release policy ("compcode") - see Appendix B for details. Additional descriptions and notes on the compensation flow releases are provided for certain reservoirs for information only. Data on mean monthly reservoir spill, augmentation releases and freshets should be obtained from the appropriate reservoir operating authority.

3. Quantifying Artificial Influences

As described in Section 2 the databases of abstraction licences, discharge consents and reservoir releases provide all the necessary information to be able to adjust the natural low flow statistics. In the absence of actual data for influence (provided by the NRA), it is necessary to be able to predict the monthly volumes. Methods for predicting monthly influences have been developed as part of NRA R & D Report 274 (Bullock *et al.*, 1994). These methods are summarised in the following sections.

3.1 ABSTRACTIONS FROM SURFACE WATER SOURCES

It is estimated that less than half of abstraction licences possess actual abstraction data. Those that do are principally the larger abstractions for public water supply, spray irrigation and industrial purposes. Although these larger licences dominate the impact of abstractions upon low flows in moderate and larger sized catchments, the cumulative impact of numerous small (and unquantified) abstractions can exert a significant impact in smaller, and more rural, catchments. Therefore, there is a requirement for procedures to predict actual monthly abstraction quantities in the absence of real data. These procedures can be summarised as follows:

1. Identify an appropriate uptake factor for each purpose covered by the licence. The uptake factor is the proportion of the total licensed abstraction quantity which is assumed to be actually abstracted. Uptake factors and monthly distribution factors will each vary with purpose of abstraction and may vary geographically within England and Wales.

2. Apply the uptake factor to the total licensed quantity for a given purpose to derive the total actual annual quantity for each purpose;

3. If the licence provides a percentage return value then this should be applied to the annual quantity.

4. Distribute the predicted volume throughout each month to predict a monthly abstraction rate using monthly distribution factors the proportion of the total volume abstracted in each month. The way in which the volume is distributed is dependent upon the purpose and seasonality of the abstraction.

Examples of uptake factors for different NRA Regions are given in Table 3.1, which have been identified from annual licences and Section 201 abstraction returns for 1991.

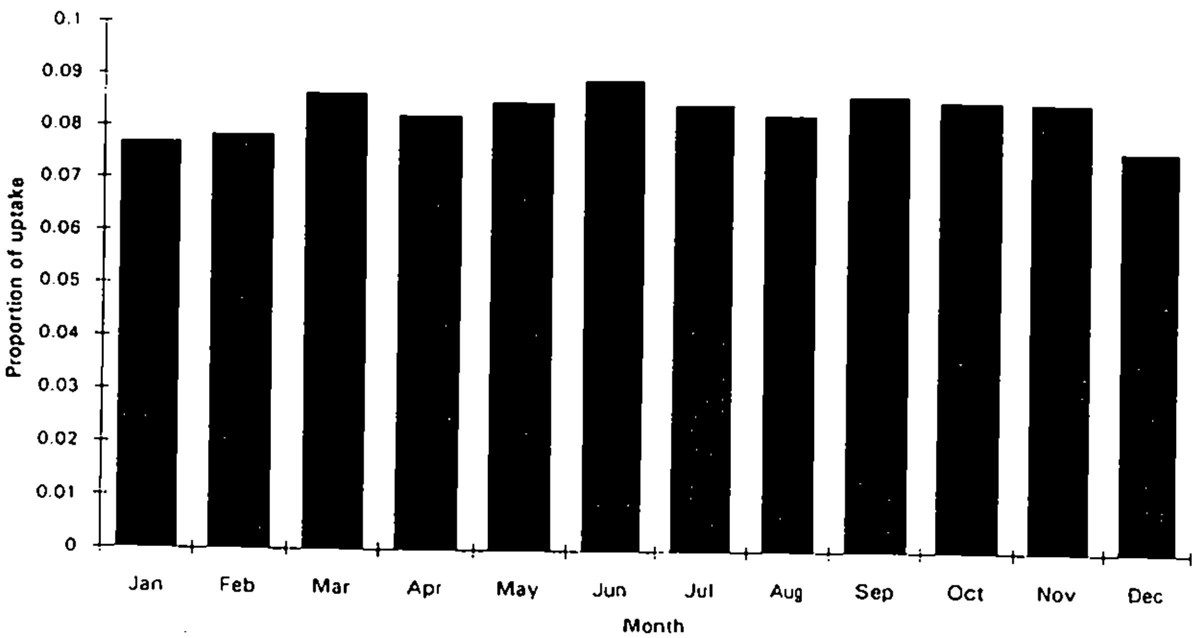
Table 3.1 *Provisional uptake factors by purpose and by Region*

	A	N	NW	ST	S	SW	W	WX	Y	NATIONAL
Spray irrigation	0.59	0.13	0.23	0.34	0.19	0.47	0.34	0.20	0.46	0.49
Cooling	0.25	0.20	0.46	0.51	0.13	0.78	0.99		0.63	0.68
Industrial processes	0.23	0.58	0.45	0.41	0.59	0.98	0.52	0.62	0.38	0.53
Public water supply	0.65	0.51	0.64	0.46	0.49	0.53	0.77	0.54	0.54	0.73
General agriculture	0.28		0.50	0.59	0.36	1.00	0.89	0.82	0.15	0.55
Fish farming	0.55	0.82	0.47	0.36	0.46	0.98	0.91	0.75	0.65	0.78
Undefined			0.39	0.53	0.32	1.00	0.61	0.34		0.78
Hydro-electric power			0.74	0.13	0.47	0.86	0.93		0.22	0.67
All purposes	0.54	0.52	0.58	0.44		0.83	0.87	0.64	0.53	0.70

These uptake factors should be used as a guide only as a result of limitations and errors in the data. R&D Note 274 recommended that more representative uptake factors should be used based on more detailed regional analysis of abstraction licences.

The total abstracted quantity needs to be distributed throughout the period of abstraction as indicated on the licence. The way in which the abstraction is distributed will depend on the purpose. Provisional monthly distribution factors have been identified from historic abstraction data for different purposes as illustrated in Figure 3.1. Examples of these monthly distribution factors are illustrated in Table 3.2. The monthly distribution factors for three regions for different purposes are given in R&D Note 274 (Bullock et al., 1994) although users are strongly urged to develop representative values for their region using the procedures outlined in this R&D Note.

(a) industrial processes



(b) spary irrigation

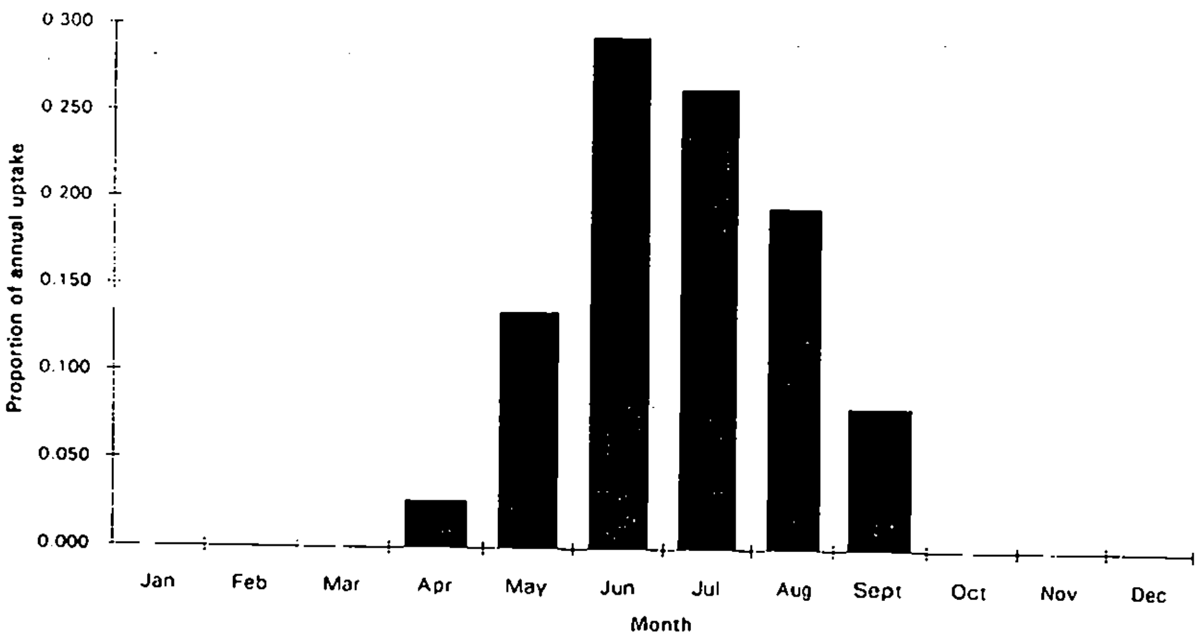


Figure 3.1 *Abstraction profiles for different purposes*

Table 3.2 *Monthly distribution factors for annual licences for different purposes*

		MONTH											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PURPOSE													
INDUSTRIAL	$\bar{x}$	0.077	0.078	0.087	0.082	0.085	0.090	0.085	0.083	0.086	0.085	0.085	0.076
	σ	0.013	0.009	0.010	0.006	0.006	0.007	0.009	0.013	0.009	0.009	0.006	0.011
PUBLIC WATER SUPPLY	$\bar{x}$	0.083	0.076	0.084	0.082	0.088	0.085	0.089	0.088	0.082	0.084	0.082	0.080
	σ	0.011	0.011	0.012	0.010	0.009	0.008	0.012	0.009	0.011	0.011	0.010	0.008
COOLING	$\bar{x}$	0.084	0.088	0.087	0.082	0.086	0.088	0.082	0.089	0.083	0.083	0.083	0.073
	σ	0.018	0.021	0.019	0.009	0.017	0.010	0.017	0.040	0.015	0.015	0.014	0.010

The data presented in Table 3.2 can be simplified from twelve monthly distribution factors to a single parameter (referred to as the minimum monthly factor) if it is assumed that the monthly abstraction profiles are symmetrical such that they can be represented by an isosceles triangle upon a rectangular base (the triangular components being of varying height and with or without a rectangular base depending on the value of the minimum monthly factor). From Figure 3.1 it can be seen that this is a valid assumption.

The value of the minimum monthly factor can be calculated as the lowest of the monthly distribution factors (Table 3.2) divided by 0.083 (being 1/12). This minimum monthly factor determines the height of the rectangular base as illustrated in Figure 3.2 based on example below where predicted monthly abstraction rates are calculated for a licence where 50% of the licensed annual abstraction of 2000 Ml is abstracted between April and September:

Licensed annual abstraction volume (V_L)	= 2000 Ml
Uptake factor (UF)	= 0.5
$\therefore$ predicted annual abstraction volume (V_A)	= 1000 Ml,
which is equivalent to a mean abstraction rate	= 1000/183
over licence period	= 5.5 Ml d^{-1}.
If the minimum monthly factor	= 0.1,
then the minimum monthly abstraction rate over licence period	= 0.5 Ml d^{-1}

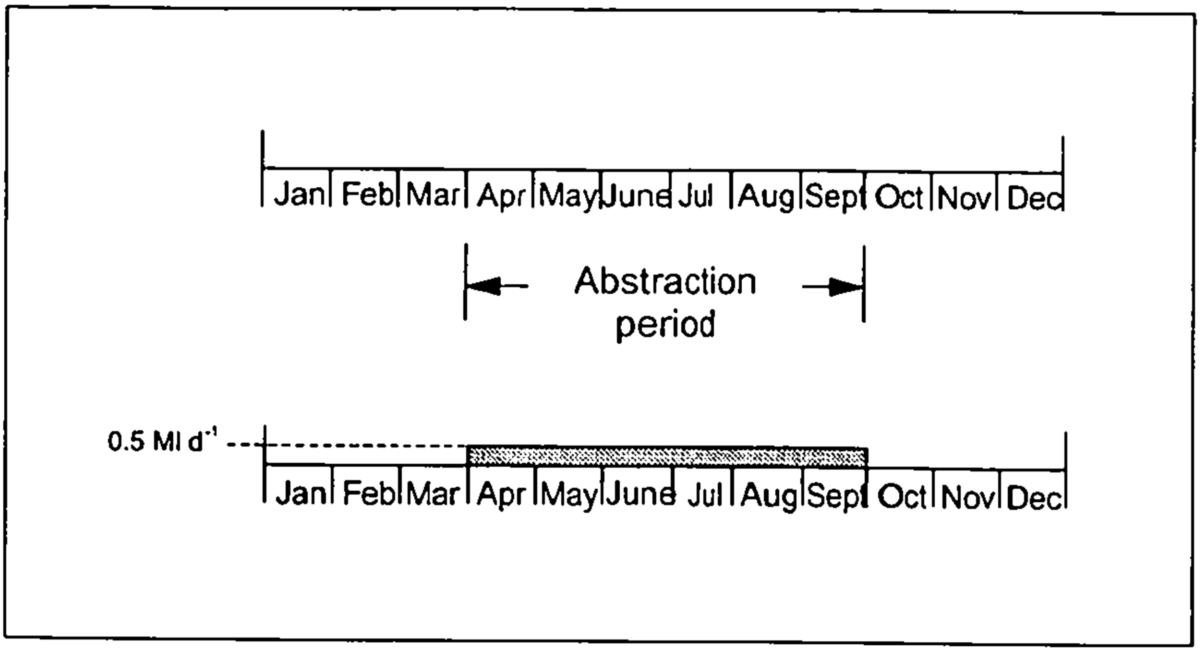


Figure 3.2 *Illustration of prediction of monthly abstraction rates by assuming triangular profiles (base component)*

The volume to be distributed as the triangular component is given by

Volume (V_T) = predicted annual abstraction volume - minimum monthly volume

In this example:

$$V_T = 1000\,(1 - 0.1) = 900 \text{ Ml}$$

The volume is represented by an isosceles triangle and the location of the apex of the triangle is equidistant between the first day of the start month of the abstraction period and the last day of the end month. The height of the triangle (h), representing the maximum monthly factor, is therefore determined by the volume of the triangular components and the abstraction period (in days) as given by:

$$h = \frac{\text{abstraction volume (Ml)}}{0.5 \text{ duration of abstraction period (days)}}$$

$$h = \frac{900}{0.5 \times 183}$$

$$= 9.8 \text{ Ml d}^{-1}$$

and the peak abstraction rate = 10.3 Ml d^{-1}

The volume of the triangular component is converted to monthly mean values according to the slope of the profile. This stage is illustrated in Figure 3.3.

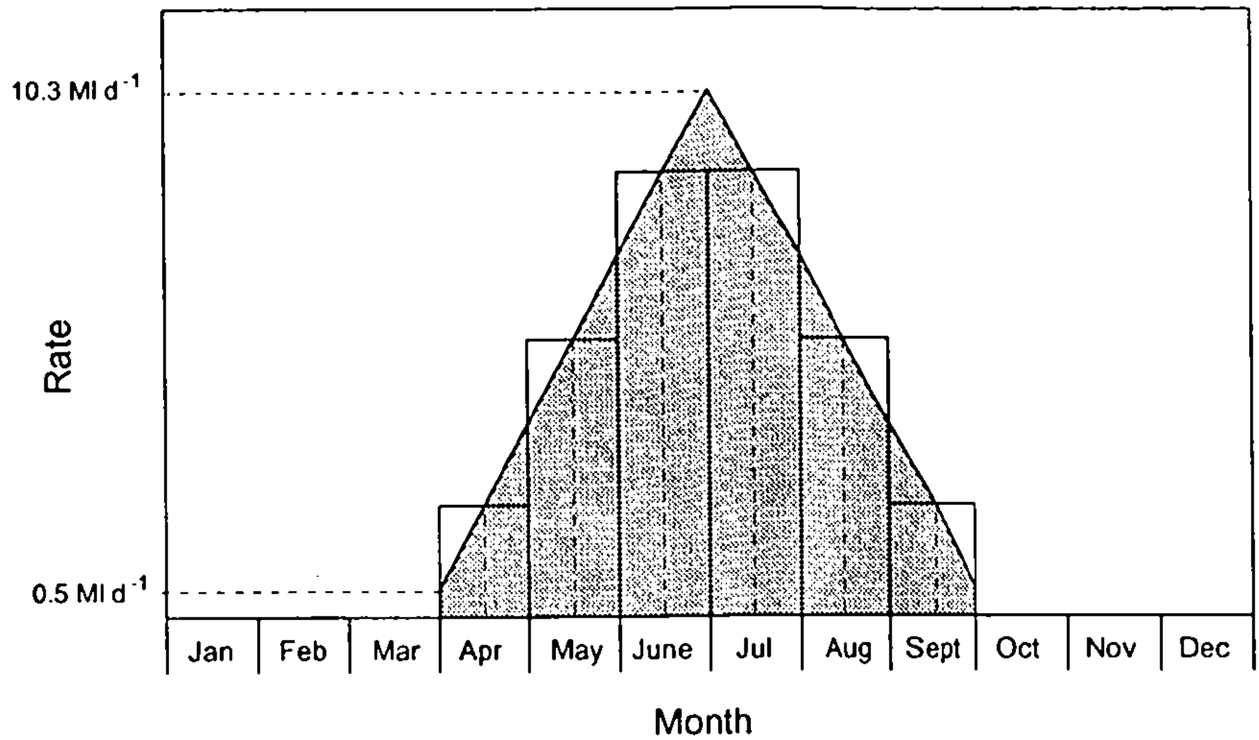


Figure 3.3 *Illustration of prediction of monthly abstraction rates by assuming triangular profile (triangular component)*

If the actual abstraction volume is to be distributed as a constant rate throughout the abstraction period, then the minimum monthly factor is set to 1.0 (that is there is no triangular component). Recommended values for the minimum monthly factor for different purposes, are presented in Table 3.3.

Table 3.3 *Recommended values of minimum monthly factors*

Purpose	Minimum monthly factor
Spray irrigation	0.0
Industrial	1.0
Public water supply	1.0
Cooling	1.0
General agriculture	1.0
Fish farming/mineral washing	1.0

In summary, monthly actual abstraction volumes can be predicted by three steps: first, the selection of an appropriate uptake factor; second, aplication of the uptake factor to the licenced annual quantity according to purpose and Region with adjustment by the percentage return to account for returns at the site of abstraction not accounted for by a linked discharge consent; third,the distribution of the annual abstraction volume to monthly abstraction volumes by application of a minimum monthly factor according to purpos eand region. This method assumes that individual licence holders abstract in accordance with the mean behaviour of all abstractors for a given purpose with a particular region.

3.2 ABSTRACTIONS FROM GROUNDWATER SOURCES

The abstraction licences which authorise abstractions from groundwater sources provide the same information relating to the total annual licensed quantities as those of surface water abstractions. However, abstractions from groundwater sources do not have an immediate impact on the flows in the rivers as a result of the complex behaviour of aquifers to groundwater pumping. For an individual well, the impact of the abstraction on the river flow is dependent upon the following factors:

(i) the bulk aquifer hydrogeology and geometry;

(ii) the distance from the stream;

(iii) the seasonality of pumping;

(iv) the pumping rate;

(vi) the degree of hydraulic connection between the stream and aquifer;

(v) features such as swallow holes and spring lines.

Items (i), (vi) and (v) are impossible to characterise on a regional basis due to their localised nature and the lack of regional databases of variability/occurence.

The solution taken for predicting the impact of groundwater abstractions on the low flow statistics was to adopt a distributed form of the Jenkins solution of the Theis analytical model. A number of analytical solutions are available for calculating the impact of single or groups of boreholes on adjacent shtreams. The Theis model is the simplest of the analytical models available for predicting the impact of groundwater abstractions on stream flows and requires a minimum amount of input data for describing the aquifer. As a result, it is suitable for implementation on a regional scale.

3.2.1 Assumptions of Theis Model

The analytical solution of the differential groundwater flow equations is based on a number of simplifications to linearise the problem and provide solvable boundary conditions. The conceptual representation of the aquifer/stream systems used in the Theis model is shown in Figure 3.4.

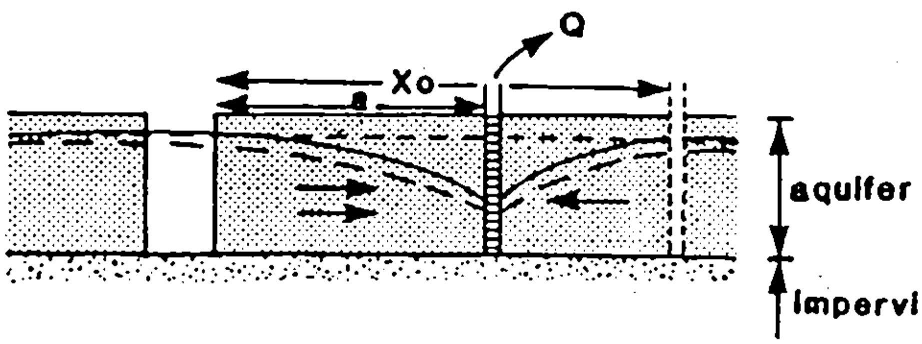


Figure 3.4 Conceptual model of the Theis analytical solution

The principal assumptions and simplifications within the Theis model are as follows:

1. The aquifer is isotropic, homogeneous and infinite in areal extent;

2. In cases of unconfined aquifers the head gradients are small, so that the vertical flow components may be neglected and only horizontal flow is considered. This is the Dupuit Forchheimer assumption;

3. The Transmissivity (T) and Storativity (S) remain constant in time;

4. The borehole is screened over the entire depth of the aquifer;

5. The rate of pumping is constant with time;

6. The temperature of the stream is equal to that of the groundwater, and is assumed to be constant over time;

7. Water is released instantaneously from storage in the aquifer;

8. The variation of water level in the stream caused by changes in discharge is neglected;

9. The stream represents the sole source of recharge, thus recharge from infiltrated precipitation can be ignored;

10. The stream is linear and infinite in extent.

The stream fully penetrates the aquifer and is in perfect hydraulic contact (ensuring Dupuit flow and a solvable stream/aquifer boundary condition). The hydraulic connection between the aquifer and the stream affect the rate at which water is transferred and also the direction of the transfer. Typical aquifer-stream connections are illustrated in Figure 3.5. The bed of the stream has resistance which is associated with the unconsolidated layers of fluvial deposits. These layers may have much lower hydraulic conductivities than those of the bulk aquifer. This approach of perfect hydraulic contact can give rise to over estimation of stream depletion due to the omission of the streambed resistance and the Dupuit flow assumption.

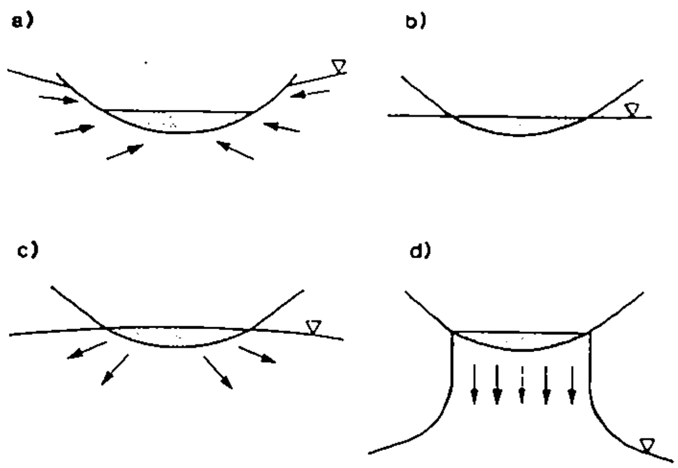


Figure 3.5 Aquifer-stream hydraulic connections

Within the Theis solution, the groundwater flow equation:

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} = \frac{S}{T}\frac{\partial h}{\partial t}$$

is solved with respect to the general boundary conditions:

$$h(x,\pm\infty,t) = 0$$

$$h(x,y,\infty) = 0$$

$$h(\infty,y,t) = 0$$

thus ensuring the system is closed in both space and time, the borehole boundary condition,

$$r\frac{\partial h}{\partial r}\Big|_{r\to 0} = \frac{Q}{2\pi T}$$

and the following boundary conditions at the stream/aquifer interface:

As the stream is in direct hydraulic contact with the aquifer the head in the aquifer is equal to the head in the stream at x=0, which in turn is constant yielding the boundary condition:

$$\frac{\partial h}{\partial x}\Big|_{x=0} = h(0,y,t)$$

The form in which the Theis solution predicts the impact in terms of the SDF (q/Q), the ratio of stream depletion volume to pumped volume, is given by:

$$\frac{q}{Q} = \mathrm{erfc}\left(\frac{1}{2\tau}\right)$$

Where:

τ = dimensionless time; defined as

$$\tau = \frac{1}{a}\sqrt{\frac{tT}{S}}$$

T = Transmissivity ($m^2\ s^{-1}$)
S = Storativity
t = time
a = distance from well to stream (m)

and

erfc(x)= the complementary error function of x.

The input parameter required are: a, T, S and the pump rate, Q. Q is required to rescale the calculated SDF to yield a nett influence volume.

For an intermittent pumping regime, the reduction in stream flow will continue after pumping has stopped. By using the method of superposition (Jenkins, 1970) it is possible to estimate the impact of a sequence of pumping events over irregular periods. The method of superposition assumes that a pumping well continues to pump past the end of the pumping period, but at the end of the pumping period, an imaginary well at the same location starts to recharge the aquifer at the same rate as the pumping well is discharging. The recharge equation can be represented by the stream depletion equation simply by changing the sign. The rate of stream depletion at any time after pumping ends is therefore equal to the difference between the depletion rate that would have occurred if pumping had continued and the augmentation rate of the imaginary recharge well.

When applied within a catchment the Theis model is distributed around all groundwater abstraction sites and run, on a monthly timestep, for 50 years (to enable equilibrium to be reached). The inputs are the distance from the stream (a), Transmissivity (T), Storativity (S) and the monthly abstraction profile. The 12 monthly SDF values from the last year of simulation are applied to the monthly abstraction volumes which can then be used in the construction of the artificial influence profile.

3.2.3 Sensitivity of Theis Model

The sensitivity of the stream depletion factor to do changes in the ratio of T/S can be summarised as follows:

1. The magnitude of the SDF response increases with increasing T/S. This is as would be expected both intuitively and from analysis of the form of the solution;

2. The response of the Theis solution to an incremental change in T/S is sensitive to the magnitude of T/S ratio. This sensitivity is greater for lower T/S values and greater distances from the stream and is more important for periodic rather than constant rate abstractions;

3. The Theis solution is most efficient for simulating the impact of groundwater abstraction upon low flows when the field conditions approximate the ideal conditions used to derive the solution.

3.3 DISCHARGE CONSENTS

The overall actual mean monthly discharges for each month are required in order to make adjustments to the low flow statistics. Where the consent covers more than one site at different locations on the river, than the actual monthly discharges for the site should be used if the location of interest lies between the upstream and downstream discharge sites

In the absence of actual monthly discharge data, the predicted mean monthly discharge is represented by the dry weather flow. This statistic is the design criteria for the works and as such represents only a crude guide to the true population, per capita water use, industrial effluent flows to sewer and mains leakage. It also does not take into account storm discharges although these are not an issue when assessing the volumetic impact on low flows.

3.4 IMPOUNDING RESERVOIRS

The method for adjusting for impounding reservoirs is equivalent to replacing natural river flows and artificial influences upstream of the dam site by twelve monthly reservoir release flows which combine mean monthly compensation flows, reservoir spill and augmentation releases or freshets if appropriate. Due to the variability in operating policies of reservoirs, illustrated in Figure 3.6, methods for predicting monthly reservoir release volumes have not been developed.

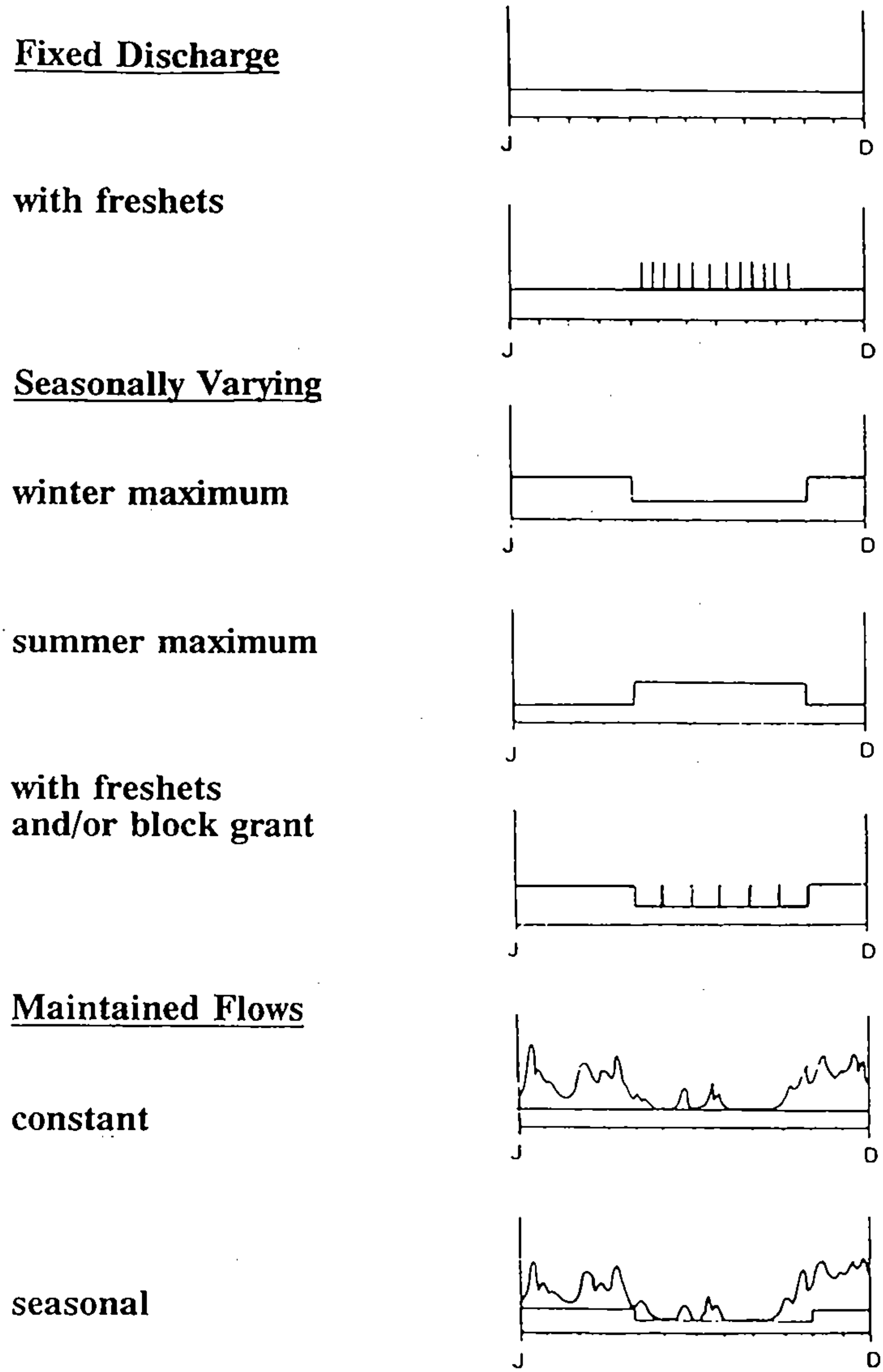


Figure 3.6 *Reservoir release profiles*

4. Construction of Monthly Influence Profiles

As discussed in previous Sections, in order to adjust the natural low flow statistics at an ungauged location, it is necessary to define the cumulative impact of all upstream artificial influences. The net impact of these artificial influences in each month can be represented by a monthly influence profile which allows the seasonal variations in certain operating regimes to be taken into account. The three key steps to the construction of a monthly influence profile at a location, are summarised as follows:

1. identification of all occurrences of artificial influences upstream of the ungauged site;

2. quantification of monthly abstraction, discharge and reservoir impacts for each identified artificial influence;

3. summation of monthly abstraction, discharge and reservoir impacts at the location.

4.1 IDENTIFICATION OF UPSTREAM OCCURRENCES OF ARTIFICIAL INFLUENCES

It is necessary to interrogate existing map and database sources to identify all upstream occurrences of artificial influences, with associated attributes as described in previous Sections. If these procedures are being applied manually, then only the more significant influences might be considered.

4.2 QUANTIFICATION OF IMPACTS FOR EACH ARTIFICIAL INFLUENCE

Once the location of influences is obtained it is then necessary to obtain mean monthly impacts of abstraction, discharge and reservoir impacts for each individual artificial influence. As a general rule, actual measured data should be used in preference to predicted data. However, actual data does not exist in all circumstances and hence there is a requirement to use predicted data (discussed previously in Section 3).

4.2.1 Surface Water Abstractions

The licenced abstraction quantities for the licences should be used in the following circumstances:

1. The overall actual mean monthly quantity for each month, by purpose and site, is the basic data unit which should be used wherever possible;

2. If actual data for the overall licence are the only available data, then these data could be distributed amongst the sites in accordance with the licensed annual quantities at different sites;

3. In the absence of actual data, then predicted monthly quantities (either overall, or site should be calculated, based on purpose and Region;

4. It is important to note whether or not the abstraction licence is linked to a discharge consent; if not, then an adjustment should be made for returns by application of the factor;

5. Seasonal licence periods must be taken into account on each overall licence or site component. Revoked licences should be discounted;

6. As Micro LOW FLOWS produces steady state flow statistics, licence conditions relating to abstraction cessation associated with minimum flow requirements can not be incorporated.

4.2.2 Groundwater Abstractions

The impact of a groundwater abstraction on low flows should be assessed by applying a time series analytical solution to evaluate the impact in terms of a monthly Stream Depletion Factor (SDF), as follows:

1. The 12 monthly abstraction rates for the site should be analyzed to identify the start month of abstraction and the period of abstraction in a year (first and last month when abstraction takes place);

2. The abstraction rate should then be averaged over this period to give a mean abstraction rate;

3. The values of storativity and transmissivity should be taken from values assigned to the aquifer unit which should be quantified in discussion with local hydrogeologists;

4. The distance of the borehole from the stream should be calculated;

5. With these inputs the analytical solution is run for a sufficient number of years to ensure the solution has reached equilibrium;

6. The 12 monthly SDFs from the last year of simulation are then multiplied by the mean actual or predicted monthly abstraction rate to generate the 12 monthly abstraction influences for the site;

7. The procedure for adding these monthly influences to the abstraction influence profile and updating the downstream influence profile will then be the same as that for surface water licences.

This procedure has the rationale of distributing the impacts of a constant groundwater abstraction to variable monthly impacts according to aquifer properties, and may also extend the impact of a seasonal groundwater abstraction throughout the year.

4.2.3 Discharge Consents

In the case of discharge consents, then the same principles apply as for abstraction licences.

1. The overall actual monthly discharges for each month should be used if available;

2. If actual data for the overall consent are the only available data, then it is necessary to distribute the consented monthly discharges amongst the site in accordance with the consented annual discharges at different sites;

3. In the absence of actual data, then predicted monthly discharges (either overall or fot the site) should be calculated based on the dry weather flow;

4. Revoked discharge consents should be discounted;

5. Due to complexities associated with their incorporation, consents which incorporate flow or quality conditions cannot be represented within Micro LOW FLOWS.

4.2.4 Impounding reservoirs

The natural flow at a site is replaced by twelve monthly reservoir release flows (RR_k), therefore all abstractions and discharges upstream of the reservoir should be ignored. The influence within a month is the sum of the release volume within the month and the inverse of the monthly flow duration curve within that month.

4.3 SUMMATION OF MONTHLY ABSTRACTION, DISCHARGE, AND RESERVOIR IMPACTS

The monthly influence profile at an ungauged (or even gauged site) is the net balance for any given month, of all upstream abstractions, and positive values of discharges and reservoir releases. The calculated monthly influence profile can be i) negative in all months in a catchment in which abstractions exceed discharges throughout the year, ii) positive in all months in a catchment in which discharges exceed abstractions throughout the year or iii) positive and negative in different months in more complex catchments, particularly when seasonal abstractions are significant.

In the case of a catchment containing only abstractions and discharges, the monthly artificial influence profile can be simplified to:

$IP_k = \text{Discharges}_k - \text{Abstractions}_k$

where k = months 1 to 12

However, in the case of there being an upstream reservoir, it is essential to discount all abstractions, discharges (ABS_{UI}, DIS_{UI}) and other reservoirs located upstream of the impoundment, and all natural flow contributions from the catchment upstream of the impoundment.

In practice, exclusion of the reservoired portion of the catchment can be achieved by drawing an appropriate catchment boundary and calculating catchment characteristics for the portion of the (natural) catchment only that occurs below the impoundment. This cannot be achieved in this manner where automatic catchment boundary definition methods are applied (as in Micro LOW FLOWS or with Digital Terrain Models), therefore an accounting solution is applied to implement reservoir impacts at a design site downstream of the reservoir.

5. Micro LOW FLOWS Implementation

The principal developments for the estimation of artificially influenced low flow statistics within Micro LOW FLOWS can be summarised as:

1. Estimation of the natural mean flow, annual flow duration curve and MAM(7) remain as within Version 1.31, with software modifications to estimate natural monthly mean flows, monthly flow duration curves and mean monthly minima;

2. Construction of the monthly artificial influence profile for all upstream influences including application of the Theis solution for simulating groundwater impacts;

3. Combination of the estimated natural low flow statistics with the monthly artificial influence profile to estimate artificially influenced low flow statistics. Micro LOW FLOWS specifically generates natural and artificial estimates of:

   (i) mean flow,

   (ii) flow duration curve,

   (iii) mean monthly minima and MAM(7).

   The estimated flow duration curves can be interrogated to derive flows from input percentiles or percentiles from input flows.

The principal developments for the construction of the monthly influence profile within Micro LOW FLOWS can be summarised as:

1. Development of database structure for archiving abstraction, discharge and reservoir data;

2. BULKDATA facility to load data into databases from pre-formatted input files;

3. Editing facilities to alter loaded data;

4. Facility to add, delete and move individual artificial influence features, with associated database updates;

5. Facility to predict monthly abstraction data in the absence of actual data;

6. Facility to download artificial influence databases;

7. Capability to construct a monthly influence profile at an individual river stretch based on influences linked to that stretch;

8. Capability to construct a monthly influence profile for each river stretch based on all artificial influences upstream of that stretch.

In order to make adjustments to the natural low flow statistics, 12 monthly influence volumes for each abstraction site held for each artificial influence are required. Actual monthly rates are used where available. In the absence of actual data, Micro LOW FLOWS can predict abstractions and discharges using information given on the licence/consent. In the case of abstractions, from groundwater sources the Theis analytical solution, using the Jenkins superposition technique for intermittent abstractions, is used to analyse the 12 monthly abstraction rates for the site. The algorithm runs on a monthly (30 day) time step and, for an individual groundwater abstraction site, will require input of:

(i) the twelve monthly abstraction rates for the site, these will either be actual return data or predicted data;

(ii) aquifer parameters of Storativity (S) and Transmissivity (T): A set of default values are provided within Micro LOW FLOWS, which can be overwritten;

(iii) distance from the stream (BOREDIST), which is calculated within the program

With these inputs the analytical solution is run on the monthly time step for a time sequence of 50 years to ensure the solution has reached equilibrium. The 12 monthly SDFs from the last year of simulation are extracted and applied to the monthly abstraction volume as calculated from the monthly abstraction rates for the site. The resultant 12 monthly influence volumes represent the estimated influence profile for the groundwater abstraction site.

The major assumptions of the Micro LOW FLOWS implementation of the Theis solution are:

(i) The mean pumping rate within a pumping period is used within the solution;

(ii) If an abstraction is seasonal that seasonality is deemed to be periodic with an annual periodicity;

(iii) An abstraction borehole is assigned to one stretch with the total impact associated with that one stretch;

(iv) In all cases the equilibrium impact is estimated;

(v) Storativity and Transmissivity values are defined by the user in the absence of a spatially referenced hydrogeological classification of aquifer properties.

References

Boorman, D.B. & Hollis, J.M. 1990. Hydrology of Soil Types. A hydrologically-based classification of the soils of England and Wales. MAFF Conference of river and coastal engineers, Loughborough University.

Boorman, D.B., Hollis, J.M. & Lilley, A. 1991. The production of the Hydrology of Soil Types (HOST) data set. BHS Third Symposium. Southampton 6.17-6.13.

Bullock, A., Gustard, A., Irving, K.M. & Young, A.R. (1994). Low flow estimation in artificially influenced catchments. National Rivers Authority R&D Report No. 257.

Gustard, A., Bullock, A., Irving, K.M. & Young, A.R. (1996). Introduction to Hydrology. NRA Training Course Reports 1-5.

Gustard, A., Bullock, A. & Dixon, J.M. (1992). Low flow estimation in the United Kingdom. Institute of Hydrology Report No. 108.

Gustard, A., Cole, G.A., Marshall, D.C.W. & Bayliss, A.C. (1987). A study of compensation flows in the United Kingdom. Institute of Hydrology Report No. 99.

Sekulin, A.E., Bullock, A., & Gustard, A. (1992). Rapid calculation of catchment characteristics using an automated river network overlay technique. Water Resources Research Vol. 28, No. 8, pp. 2102-2109.

APPENDIX A

LOW FLOW ESTIMATION IN ARTIFICIALLY INFLUENCED CATCHMENTS

TRAINING COURSE

Synidcate Exercise

Construction of Monthly Artificial Influence Profiles

Construction of Monthly Influence Profiles

The objective of this syndicate exercise is to construct a monthly influence profile for a catchment containing two surface water abstractions and a sewage treatment works.

ABSTRACTION A is licensed to abstract 2000 Ml during the year for industrial purposes with no seasonal restriction. No data are available on actual abstractions.

ABSTRACTION B is licensed to abstract 500 Ml for spray irrigation purposes during the period May - October. No data are available on actual abstractions.

SEWAGE TREATMENT WORKS C has a design dry weather flow of 0.075 $m^3 s^{-1}$.

1. USING AUTHORISED QUANTITIES

1. Using Table 1, construct the monthly profiles for the three separate artificial influences, in $m^3 s^{-1}$.

2. Then, construct a monthly nett influence profile of the combined influences (Table 2), noting that abstractions are negative and discharges are positive.

3. Draw the monthly nett influence profile on graph paper, and write a short description of the likely impact of the artificial influences.

Table 1

MONTH	J	F	M	A	M	J	J	A	S	O	N	D
Abstraction A												
Abstraction B												
STW C												

Table 2

MONTH	J	F	M	A	M	J	J	A	S	O	N	D
Nett Influence												

Impact of influences:

2. USING PREDICTED QUANTITIES

The previous exercise constructed a monthly influence profile using authorised quantities; to illustrate the case of no actual quantities being available, the following exercise uses predicted abstraction quantities.

Assuming the authorised abstractions given previously, complete Table 3 with the relevant information required for predicting abstraction quantities. Use the provisional uptake factors given in Table 4 or assume a more representative figure. In the example:

Example X is a constant abstraction for public water supply

Example Y is a summer abstraction for spray irrigation

Table 3

Abstraction	Purpose	Licensed Annual Abstraction Volume (V_L)	Uptake Factor (UF)	Start Month	End Month	Minimum Monthly Factor (MMF)
Example X	PS	3000	0.73	JAN	DEC	1.0
Example Y	SI	750	0.5	APR	SEP	0.2
Abstraction A						
Abstraction B						

Table 4 *Provisional uptake factors by purpose and by Region*

	A	N	NW	ST	S	SW	W	WX	Y	NATIONAL
Spray irrigation	0.59	0.13	0.23	0.34	0.19	0.47	0.34	0.20	0.46	0.49
Cooling	0.25	0.20	0.46	0.51	0.13	0.78	0.99		0.63	0.68
Industrial processes	0.23	0.58	0.45	0.41	0.59	0.98	0.52	0.62	0.38	0.53
Public water supply	0.65	0.51	0.64	0.46	0.49	0.53	0.77	0.54	0.54	0.73
General agriculture	0.28		0.50	0.59	0.36	1.00	0.89	0.82	0.15	0.55
Fish farming	0.55	0.82	0.47	0.36	0.46	0.98	0.91	0.75	0.65	0.78
Undefined			0.39	0.53	0.32	1.00	0.61	0.34		0.78
Hydro-electric power			0.74	0.13	0.47	0.86	0.93		0.22	0.67
All purposes	0.54	0.52	0.58	0.44		0.83	0.87	0.64	0.53	0.70

Then, complete Table 5 following the calculations using the examples given below

Table 5

Abstraction	V_L in Ml	UF	Predicted annual abstraction volume in Ml (V_A)	Mean abstraction rate (Ml d^{-1}) during authorised period	MMF	BASE COMPONENT Minimum monthly abstraction rate (Ml d^{-1})	TRIANGULAR COMPONENT Triangular component volume in Ml (V_T)	Maximum rate within triangular component (h)	Middle day of authorised period
Example X	3000	0.73	2190	6.00	1.0	6.0	0	0	365
Abstraction A									
Example Y	750	0.50	375	2.05	0.2	0.4	300	3.28	183
Abstraction B									

To obtain the monthly abstraction profiles:

1. On graph paper, plot the minimum monthly abstraction rate over the authorised period (the rectangular component);

2. Draw the triangular component for the period as an isosceles triangle which is symmetrical about the middle day of the abstraction period;

3. The monthly abstraction rate can be read off at the intersection of the triangle with the midpoint of each month, see Figure 1;

4. Calculate the base component, triangular component and total monthly abstraction in Ml d^{-1} and m^3 s^{-1}.

The following Table illustrates this procedure for Example Y.

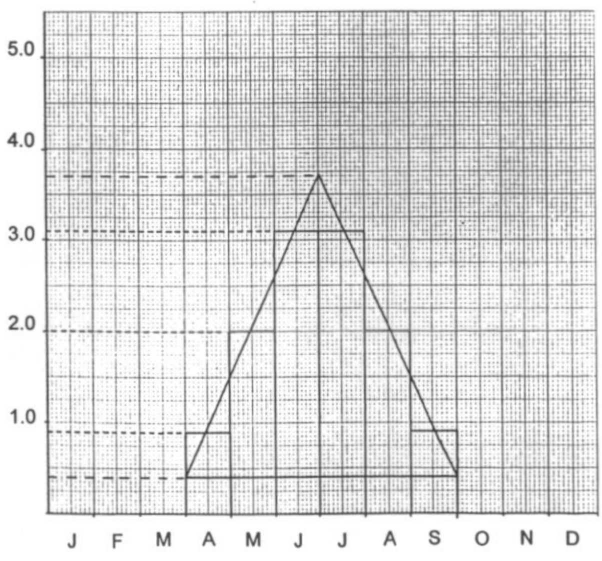


Figure 1

Within Table 5:

$$V_A = V_L \times UF \times \left[1 - \frac{\text{PRET}}{100}\right]$$

and

PRET = Percentage returned

and

the mean abstraction rate during the authorised period	=	V_A divided by the number of days between beginning of start month and end of end month (N DAYS);

and

minimum monthly abstraction rate	=	MMF x mean abstraction rate during authorised period

and

$$V_T = V_A (1 - \text{MMF})$$

and

$$h = \frac{V_T(\text{in } Ml)}{0.5 \times \text{duration of abstraction period in days}}$$

Following Example Y, then

Peak abstraction rate	=	h + minimum monthly abstraction rate
	=	3.28 + 0.4
	=	3.68

Table 6a

EXAMPLE Y	J	F	M	A	M	J	J	A	S	O	N	D
Base Component	0	0	0	0.4	0.4	0.4	0.4	0.4	0.4	0	0	0
Triangular Component	0	0	0	0.5	1.6	2.7	2.7	1.6	0.5	0	0	0
Total Predicted Monthly Abstraction in Ml d^{-1}	0	0	0	0.9	2.0	3.1	3.1	2.0	0.9	0	0	0
Total Predicted Monthly Abstraction in m^3 s^{-1}	0	0	0	0.01	0.02	0.04	.04	.02	.01	0	0	0

From your graphs, complete Tables 6b and 6c, calculating the base and triangular components, and then the total abstraction for Abstractions A and B.

Table 6b

ABSTRACTION A	J	F	M	A	M	J	J	A	S	O	N	D
Base Component												
Triangular Component												
Total Predicted Monthly Abstraction in Ml d^{-1}												
Total Predicted Monthly Abstraction in m^3 s^{-1}												

Table 6c

ABSTRACTION B	J	F	M	A	M	J	J	A	S	O	N	D
Base Component												
Triangular Component												
Total Predicted Monthly Abstraction in Ml d^{-1}												
Total Predicted Monthly Abstraction in m^3 s^{-1}												

Using the following table, construct a monthly nett influence profile of the combined predicted influences. Superimpose the predicted data on the graph showing authorised quantities. Write a short paragraph on the differences.

Table 7

MONTH	J	F	M	A	M	J	J	A	S	O	N	D
Abstraction A												
Abstraction B												
STW C												
Nett Influence												

APPENDIX B

Appendix B Micro LOW FLOWS File formats

1. INTRODUCTION

Micro LOW FLOWS V2.1 has the capability for bulk loading data associated with the following features:

(i) Abstractions
(ii) Discharges
(iii) Reservoirs
(iv) Spot Gauging
(v) Gauging Stations

Data files must be loaded onto Micro LOW FLOWS as standard unformatted ASCII files. Separate data files need to be provided for each feature type and for each Hydrometric Area. Within each file are details for the individual features, for example National Grid Reference, total annual licenced abstraction, consented daily discharge, monthly reservoir release profile etc. For the data to be loaded correctly, it is important that this information is provided in the order specified.

2. ABSTRACTION DATA FILE FORMATS

The abstraction licence database within Micro LOW FLOWS V2.1 is capable of holding data for complex licences consisting of up to 20 sites per licence and up to 10 purposes at each site. In addition the database structure enables 12 monthly actual abstraction volumes to be included for each site. The data holdings for an individual licence are divided into two components: the overall licence and the individual site licence.

Overall Licence Data

The following user-defined data are held for the overall licence:

Variable	Description	Format
OLINO	NRA licence number	A16
OLIHOLDER	name and address of licence holder	A28
OTYPE	identifier as to whether the licence is surface or groundwater	A1
OISSUE	date of licence issue	free format
OREVOKE	revocation date	free format
ONOSITE	number of sites	I2
OCLICANN	total licensed annual quantity (m^3s^{-1})	free format
OLICDAY	total licensed daily quantity (m^3s^{-1})	free format
OACTANN	total actual annual quantity (m^3s^{-1})	free format
OACTDAY	total actual daily quantity (as a maximum) (m^3s^{-1})	free format

Individual Site Licence

The following variables are held for the individual sites covered by the licence:

Variable	Description	Format
IHNO	IH licence number	I6
SGREF	grid reference of site, either metres or NGR	2 x I6
SNAME	name of site	A28
SGUNIT	ground water unit (groundwater licences only) CH Chalk UG Upper Greensand LG Lower Greensand JL Jurassic Limestone TS Permotriassic Sandstone ML Magnesian Limestone CL Carboniferous Limestone SG Sand and Gravels	A7
BOREDIST	Distance of borehole from nearest river stretch	free format
SSTOR	storativity of the groundwater unit $0.1 < SSTOR < 10$	free format
STRANS	transmissivity of the groundwater unit $0.00001 < STRANS < 0.30$	free format
SPRETP(j)	percentage of water abstraction returned at source through an unconsented discharge for a particular purpose)	free format
SMRF	minimum required flow at a prescribed flow point	free format
STHRESHQ	threshold flow at a prescribed flow point below which abstraction must cease (m^3s^{-1})	free format
SLICANN	licensed annual quantity for site (irrespective of different purposes) (m^3s^{-1})	free format
SLICDAY(i)	licensed daily quantity for site (irrespective of different purposes)	free format
SPURP(j)	purposes at site (up to 10 permitted) SI Spray Irrigation CO Cooling Water IP Industrial Processing PS Public water Supply BW British Waterways GA General Agriculture PW Private Water undertaking FF Fish Farming MD Mine Drainage UD UnDefined	
SLICANNP	licensed annual quantity for each purpose (m^3s^{-1})	free format
SLICDAYP	licensed daily quantity for each purpose (m^3s^{-1})	free format
SSDATEP	start date of abstraction for each purpose, defined as a calendar month	free format
SEDATEP	end date of abstraction for purpose, defined as a calendar month	free format
SACTMTH	actual monthly quantities for the site in each month (m^3s^{-1})	free format
SPREMTH	predicted monthly quantities for the site in each month (m^3s^{-1})	free format

Sample data for the input file for an abstraction licence (Overall and Site) are given below:

ABSTRACTIONS	Header for Abstraction data file
26	Header for Drainage area number
NRA NUMBER	OLINO
NRA HOLDER	OLIHOLDER
G	OTYPE
1968 1972	OISSUE,OREVOKE
2	ONOSITE
10. 5.	OLICANN,OLICDAY
10.1 5.1	OACTANN,OACTDAY
-1	End of licence data
505200 439000	SGREF (site 1)
First site	SNAME
Gwu1	SGUNIT
1. 2. 3. 4. 5. 6. 7.	SSTOR, STRANS, SPRET, SMRF, SLICANN, SLICDAY
.1 .2 .3 .4 .5 .6 .7 .8 .9 1. 1.1 1.2	12 x SACTMTH
SI 1.01 1.02 1 12	SPURP, SLICAN, SLICDAYP, SSDATE, SEDATE
CO 1.11 1.12 2 12	SPURP, SLICANNP, SLICDAYP, SDATE, SEDATE
-1	End of first site data
505300 440000	SGREF (site 2)
Second site	SNAME

.... etc

Repeat the above structure for each licence and component sites.

NOTE:

(1) The two header records at the top of the file are not repeated;
(2) Only named purposes need be present. The purpose (given as A2 format) must start in column 1;
(3) ALL fields must be accounted for. Unassigned character fields are left blank and -999. must be used to denote unassigned numerical fields.

A separate file is required for each drainage area.

3. DISCHARGE DATA FILE FORMAT

The structure of the discharge database within Micro LOW FLOWS V2.1 provides the capability to hold data for complex discharge consents for up to 20 sites. In addition, the database structur allows 12 monthly actual discharge volumes to be included for each site.

In common with the abstraction database, the required data holdings can be divided into two components: the overall consent and the consent for each individual site.

Overall Discharge Consent

The following user-defined variables are required for the overall consent:

Variable	Description	Format
IHNO	IH number	I6
OCONNO	NRA consent number	A16
OCOHOLD	name and address of consent holder	A28
OCNOSITE	number of sites	free format
OCPURP	consent purpose: CS Crude Sewage S Screened Sewage SS Settled Sewage TS Treated Sewage SW Storm Water overflow MD Mine Drainage CW Cooling Water FE Farm Effluent TE Trade Effluent FF Fish Farm effluent	A2
OCISSUE	consent issue date	free format
OCREVIEW	consent review date	free format
OCAVRAT	consented average discharge rate (m^3s^{-1})	free format
OCMAXRAT	consented maximum discharge rate (m^3s^{-1})	free format
OPOPEQIV	population equivalent	free format

Individual Site Consent

The following user-defined variables are required for the individual site:

Variable	Description	Format
SSITENO	site reference number	2 x I6
SGREF	grid reference of site, either metres or NGR	A28
SNAME	name of site	A20
SRECRIV	receiving river	free format
SCAVRAT	consented average discharge rate for the site (m^3s^{-1})	free format
SCMAXRAT	consented maximum discharge rate for the site (m^3s^{-1})	free format
SDDWF	design dry weather flow at the site (m^3s^{-1})	free format
SCAMTH	actual monthly discharges for each month at the site (m^3s^{-1})	free format
SPREMTH	predicted monthly discharges for each month at the site (m^3s^{-1})	free format

Sample data for the input file for a discharge consent (Overall and Site) are given below:

DISCHARGES	Header for Discharge data
26	Header drainage area no.
NRA NUMBER	OCONNO
NRA HOLDER	OCOHOLD
SS	OTYPE
1968 1972	OCISSUE, OCREVIEW
2	OCNOSITE
5. 10. 10000	OCAVRAT, OCMAXRAT, OPOPEQIV
-1	End of licence data
505200 439000	SGREF (first site)
First site	SNAME
First river	SRECRIV
1. 2. 3.	SCAVRAT, SCMAXRAT, SDDWF
.1 .2 .3 .4 .5 .6 .7 .8 .9	12 x SCAMTH
1. 1.1 1.2	
-1	End of first site data
505300 440000	SGREF (second site)

........etc

Repeat the above structure for each discharge consent and component sites.

NOTE:

(1) The two header records at the top of the file are not repeated;
(2) Only named purposes need be present. The purpose (given as A2 format) must start in column 1;
(3) ALL fields must be accounted for. Unassigned character fields are left blank and -999. must be used to denote unassigned numerical fields.

A separate file is required for each drainage area.

4. IMPOUNDING RESERVOIR DATA FILE FORMAT

Data entries for reservoirs in each hydrometric area have been loaded by Institute of Hydrology based on the information listed in IH Report 99, A Study of Compensation Flows in the UK (Gustard et al, 1987).

It is also possible to bulk load updated reservoir information. The data held are as follows:

Variable	Description	Format
RESERVOIR NUMBER	Number assigned to each reservoir for reference purposes	I6
EASTING	NGR Eastings	I6
NORTHING	NGR Northings	I6
TYPE	Code categorising primary function of reservoir: 1 Hydroelectric with compensation 2 Hydroelectric with no compensation 3 Compensation only 4 Supply and compensation 19 Supply only 16 Pumped storage 18 Regulating	I2
DATE	Date of reservoir impoundment	free format
AREA	Natural catchment area and areas drained by catchwaters (km^2)	free format
NATAREA	Natural catchment area (km^2)	free format
GROSS CAPACITY	Gross capacity of the reservoir (Ml)	free format
NET CAPACITY	Net capacity of the reservoir (Ml)	free format
MF recorded	Observed mean flow at reservoir outflow or maintained flow point ($Ml\ d^{-1}$)	free format
MF estimated	Estimated natural mean flow at reservoir outflow or maintained flow point ($Ml\ d^{-1}$)	free format
Compcode	Code categorising type of release policy: 0 Constant discharge 7 days/week 1 Constant discharge 6 days/week 2 Seasonally varying releases 3 Seasonally varying releases + freshets and/or block grant allowance 4 Constant discharge + freshets or block grant 5 Constant discharge over variable period 6 Constant discharge which varies weekly/daily 7 Constant discharge from 1 or more reservoirs 8 Variable discharge based on natural flow 10-18 As above but for maintained flow downstream 19 Seasonally varying releases and constant maintained flow downstream	free format
Compflow	Compensation flow at reservoir or maintained flow point (Mld^{-1}). Reference must be made to type of release policy.	free format
NYIELD	Net yield at the reservoir (Mld^{-1})	free format
MTHREL	12 Monthly reservoir release values	free format

An example of the input format for the reservoir data file is given below:

RESERVOIRS	Header for reservoir data
27	Header drainage area no
John O'Gaunts	Reservoir name
422103 454639	Easting and Northing (Site 1)
3. 1890. -999. .079 -999.	TYPE,DATE,TOTAREA,NYIELD,COMPCODE
-999. 555. .035 3.	COMPFLOW,NETCAP,MFEST,AUTHORITY
-999. -999. -999. 851. 450.	NATAREA,GROSSCAP,MFREC,SAAR, AE
1. -999. 3. -999. 5. -999.	Twelve monthly release values
-999. 9. -999. 11. -999.	
-1	End of reservoir marker

Repeat the above structure for each reservoir.

NOTE:

(1) The two header records at the top of the file are not repeated;
(2) Only named purposes need be present. The purpose (given as A2 format) must start in column 1;
(3) ALL fields must be accounted for. Unassigned character fields are left blank and -999. must be used to denote unassigned numerical fields.

A separate file is required for each drainage area.

5. SPOT GAUGING DATA FILE FORMAT

Micro LOW FLOWS V2.1 provides a facility for storing up to 250 spot current meter readings for a site. In order to bulk load the spot current meter data, an example of a spot gauging input file is given below:

SPOTGAUGES	Header for spot gauging data
26	Header drainage area
515100. 448200.	6-digit grid reference (site 1)
1	Number of readings
CATFOSS BECK	Name
U/S STW	Description
811021 .000 -999. -999.	Date (yymmdd), Time (hh.mm), Flow, Percentile
Comment	12-character reference text, repeat upto a max of 250
N	Y or N FDC flag
-1	End of spotgauge marker
505300. 439100.	6-digit grid reference (site 2)
2	Number of readings ...etc
BEVERLEY & SKIDBY DRAIN	
STW	
810813 10.150 .044 -999.	
STEADY	
N	
810709 10.150 .177 -999.	
STEADY	
Y	
-1	

6. GAUGING STATION DATA FILE FORMAT

Gauging station data has been loaded onto Micro LOW FLOWS V2.1 using summary information retrieved from the National River Flow Archive held at the Institute of Hydrology. The following attributes are held for gauging stations:

- i) National River Flow Archive Gauge Number
- ii) Grid Reference
- iii) Start and end year of flow record
- iv) Catchment area
- v) Observed mean flow (m^3s^{-1})
- vi) Observed low flow statistics, Q95(1) and Q50(1).

For the gauging station data to be bulk loaded, an example of the input format is laid out below:

GAUGING STATIONS	Header for gauging station data
26	Header for drainage area
26001	National River Flow Archive gauge number
West Beck	32 character name
at Wansford Bridge	32 character description
506445 455925	6-digit grid reference
2.512 .695 .507 -999. 192.000	MF, MAM7, Q95, Q50, AREA
1953.000 1974.000	STARTYEAR, ENDYEAR
-1	End of station marker
26002	
Hull	
at Hempholme Locke	
507865 449947	
3.637 .877 .552 378.100	
1961 1991	
-1	